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Groundwater flow measurements in permanently installed boreholes

Test campaign no. 11, 2015–2016

Eva Wass

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT CO

Box 3091, SE-169 03 Solna
Phone +46 8 459 84 00
skb.se

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Keywords: AP SFK-15-014, Groundwater flow.

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Abstract

This report describes the performance and evaluation of groundwater flow measurements in six selected borehole sections in permanently installed boreholes within the Forsmark investigation area. This is the eleventh test campaign performed within the monitoring program and measurements are planned to be repeated every year. The objective for these campaigns was to determine groundwater flow rates in all, at the time available, borehole sections instrumented for this purpose. An extended aim for this year's campaign was to increase understanding of the natural variation in groundwater flow that can be seen from year to year, but also changes during ongoing measurement. Frequently repeated and/or continuous measurements also provide a good picture of how the flow is influenced by e.g. rainfall or snow melt, so that these effects later can be distinguished from effects emanating from construction of the repository.

The groundwater flow rates were determined through dilution measurements during natural conditions. Measured flow rates ranged from 0.002 to 31 ml/min with calculated Darcy velocities from 1.8×10^{-11} to 1.3×10^{-7} m/s. Hydraulic gradients were calculated according to the Darcy concept and varied between 0.0003 and 1.8.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i sex utvalda borrhålssektioner i permanent installerade borrhål inom Forsmarks undersökningsområde. Detta är den elfte mätkampanjen som genomförts i moniteringsprogrammet och mätningarna är planerade att återupprepas varje år. Syftet var att bestämma grundvattenflödet i samtliga, vid denna tidpunkt och för detta ändamål, instrumenterade sektioner. Ett utökat syfte för detta års kampanj var att öka förståelsen för de naturliga variationer i flödena som kan ses från år till år, men också förändringar under pågående mätning. Frekvent upprepade och/eller kontinuerliga mätningar ger också en bra bild över hur flödena påverkas av t.ex. nederbörd eller snösmältning så att dessa effekter senare kan särskiljas från effekter av slutförvarsbygget.

Grundvattenflödet mättes med utspädningsmetoden under naturliga förhållanden i utvalda borrhålssektioner. Uppmätta grundvattenflöden låg i intervallet 0,002–31 ml/min med beräknade Darcy hastigheter mellan $1{,}8 \times 10^{-11}$ och $1{,}3 \times 10^{-7}$ m/s. Hydrauliska gradienter beräknades enligt Darcy-konceptet och varierade mellan 0,0003 och 1,8.

Contents

1 Introduction

This document reports the results gained from the groundwater flow measurements in permanently installed boreholes, test campaign no. 11, 2015-2016, which is part of the programme for monitoring of geoscientific parameters and biological objects within the Forsmark site investigation area (SKB 2007). Monitoring commenced during the Forsmark site investigations 2002-2007, and a monitoring programme was established as an independent project starting in July 2007, after completion of the Forsmark site investigation in June 2007.

The work was carried out in accordance with activity plan AP SFK-15-014 and the field work was conducted from the beginning of September 2015 to the beginning of July 2016. In Table 1-1 controlling documents for performing this activity are listed. The activity plan and the method description are SKB's internal controlling documents.

A map of the site investigation area at Forsmark including borehole locations is presented in Figure 1-1.

The original results are stored in the primary data base Sicada and are traceable by the activity plan number.

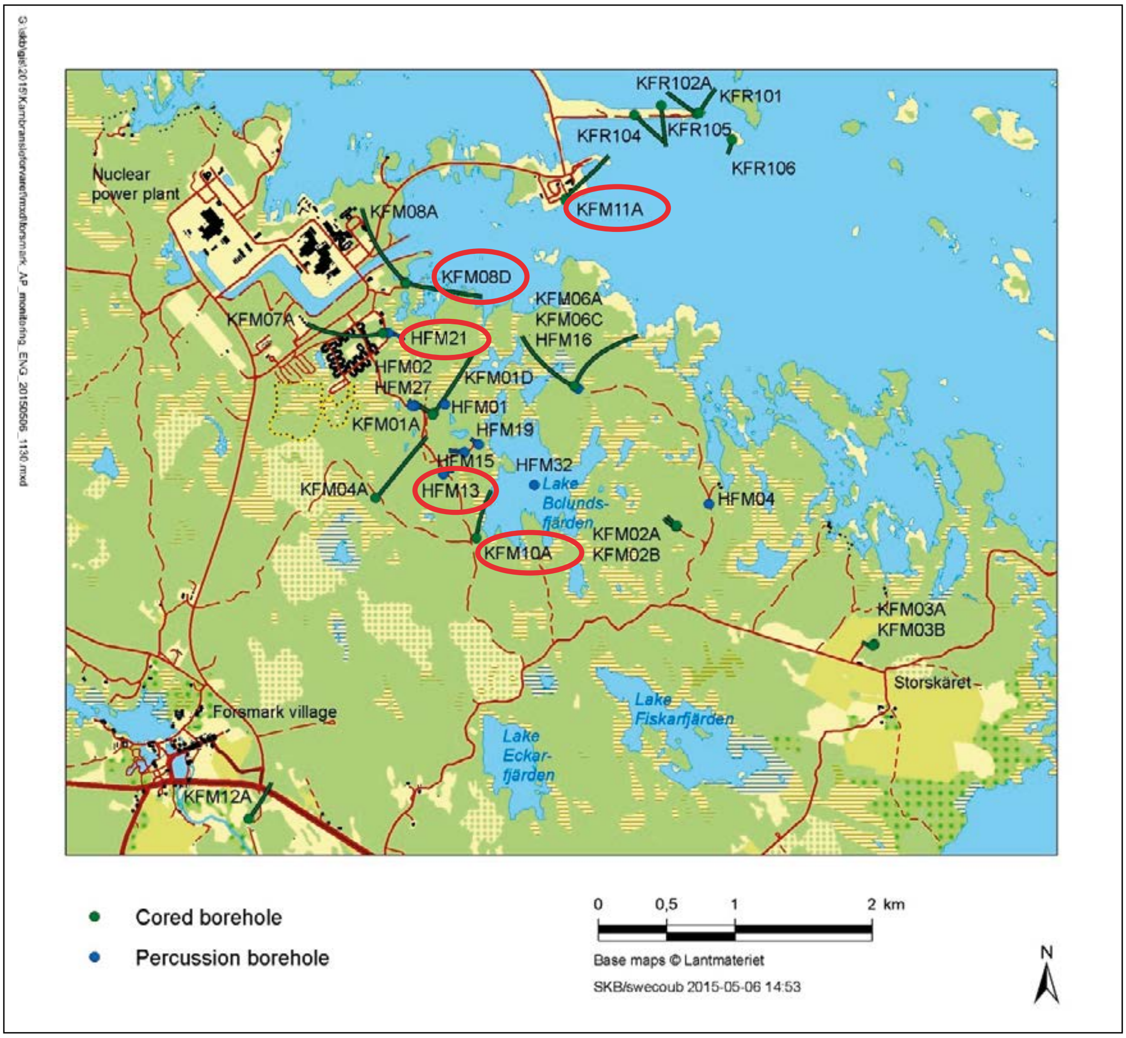

Figure 1-1. *Overview over the Forsmark area, showing locations of boreholes included in the groundwater flow monitoring program. Red markings show the boreholes measured during 2015–2016 presented in this report.*

Table 1-1. Controlling documents for performance of the activity.

Document	Number	Version
Activity plan		
Monitering av grundvattenflöde 2015–2016	AP SFK-15-014	1.0
Method description		
System för hydrologisk och meteorologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål	SKB MD 368.010	1.0

2 Objective and scope

The objective of this activity was to determine the groundwater flow in permanently installed borehole sections at Forsmark. Six selected borehole sections instrumented for this purpose were measured, cf. Table 4-1. This was the eleventh test campaign performed within the monitoring program and measurements are planned to be repeated every year. The measurements will serve as a basis to study undisturbed groundwater flow as well as to monitor changes caused by future activities in the area such as underground construction and drilling. An extended aim for this year's campaign was to increase understanding of the natural variation in groundwater flow that can be seen from year to year, but also changes during ongoing measurement. Frequently repeated and/or continuous measurements also provide a good picture of how the flow is influenced by e.g. rainfall or snow melt, so that these effects later can be distinguished from effects emanating from construction of the repository. This is the third campaign with measurements performed over longer periods.

The selection of borehole sections was made to represent different depths and types of fractures/fracture zones in the Forsmark area. The maximum number of sections was set to six due to availability of personnel and equipment.

The groundwater flow in the selected borehole sections was determined through tracer dilution measurements. The measurements may, on the whole, be regarded as performed during natural, i.e. undisturbed, hydraulic conditions. A new borehole, KFM24 (550 m), was drilled from the end of March until the middle of June 2016 in the vicinity of drillsite 8. However, this seems not to have affected the measurements in KFM08D.

3 Equipment

3.1 Borehole equipment

Each borehole involved is instrumented with 1-9 inflatable packers isolating 2-10 borehole sections. Drawings of the instrumentation in core and percussion boreholes are presented in Figure 3-1.

All isolated borehole sections are connected to the Hydro Monitoring System (HMS) for pressure monitoring. In general, the sections intended for tracer tests are each equipped with three polyamide tubes connecting the borehole section in question with the ground surface. Two are used for injection, sampling and circulation in the borehole section and one is used for pressure monitoring.

3.2 Dilution test equipment

The tracer dilution tests were performed using six identical equipment set-ups, allowing all six sections to be measured simultaneously. A schematic drawing of the tracer test equipment is shown in Figure 3-2. The basic idea is to create an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section and to sample the tracer concentration outside the borehole in order to monitor the dilution of the tracer with time.

Circulation is controlled via a down-hole pump with adjustable speed and measured by a flow meter. Tracer injections are performed with a peristaltic pump and sampling is made by continuously extracting a small volume of water from the system through another peristaltic pump (constant leak) to a fractional sampler. The equipment and test procedure is described in detail in SKB MD 368.010, see Table 1-1. The sampler was put in a plastic box together with four small bottles containing fresh water in order to prevent, or at least reduce, evaporation of water from the samples, see Figure 3-3. The tracer used was a fluorescent dye tracer, Amino-G Acid from Aldrich (techn. quality).

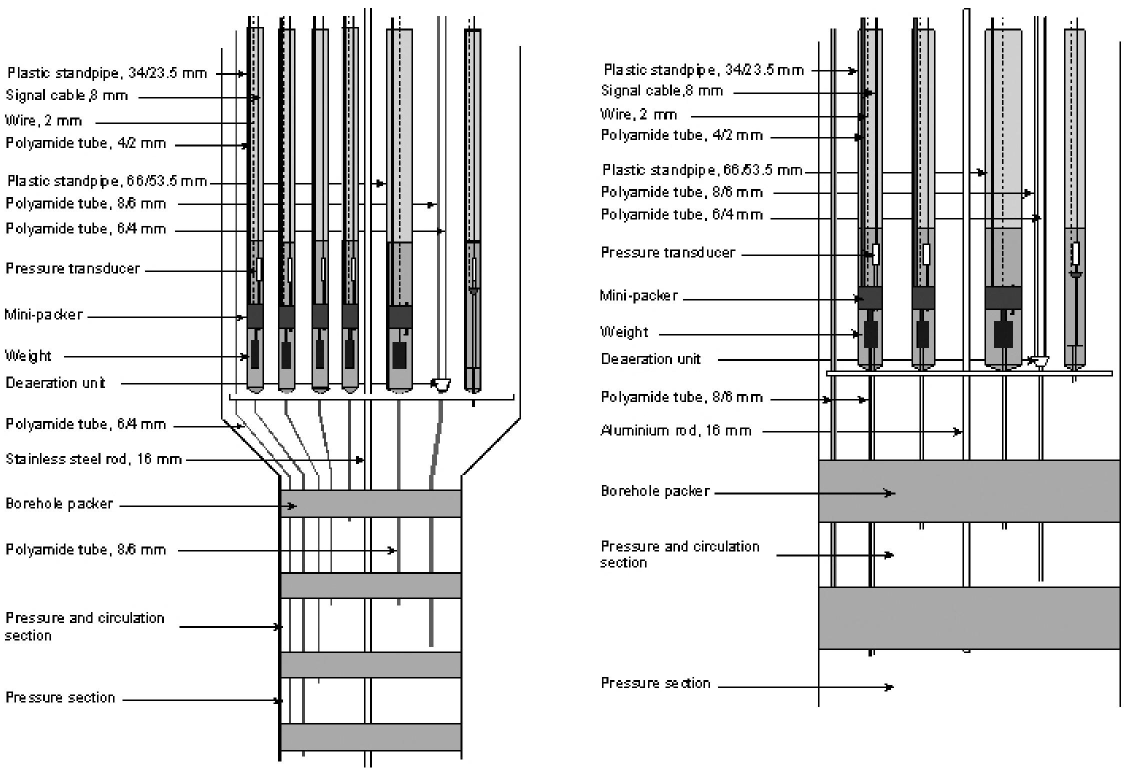

Figure 3-1. Example of permanent instrumentation in core boreholes (left) and percussion boreholes (right) with circulation sections.

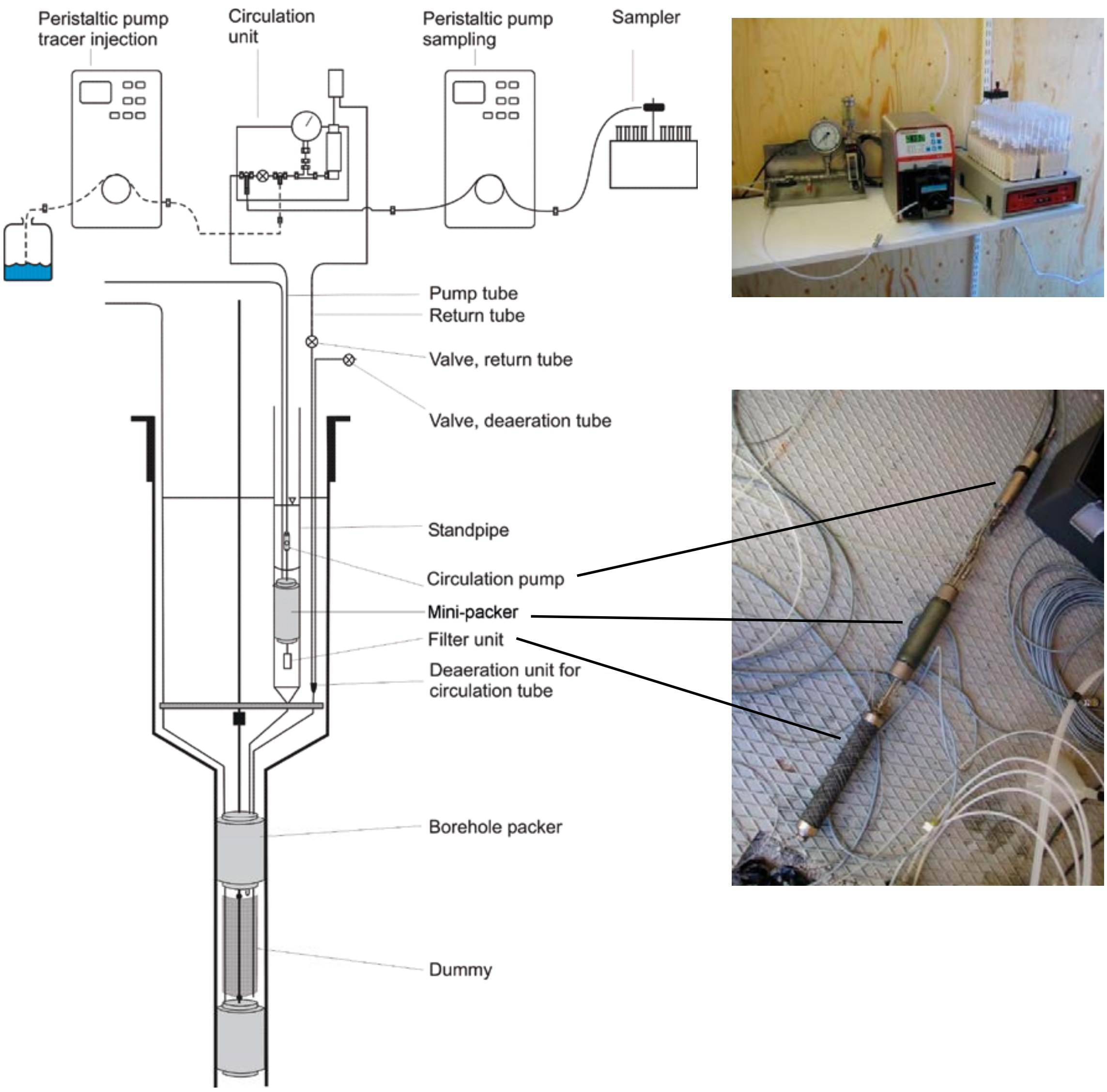

***Figure 3-2.** Schematic drawing of the equipment used in tracer dilution measurements.*

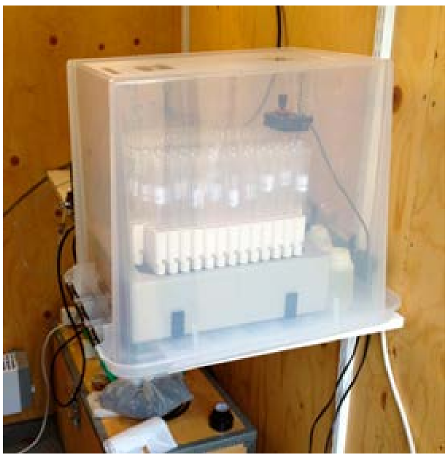

***Figure 3-3.** The sampler was put in a plastic box in order to reduce evaporation from the samples.*

4 Execution

4.1 General

In the dilution method a tracer is introduced and homogeneously distributed into a borehole section. The tracer is subsequently diluted by the ambient groundwater flowing through the borehole section. The dilution rate is proportional to the water flow through the borehole section and the groundwater flow rate is calculated as a function of the decreasing tracer concentration with time, Figure 4-1.

The method description used was "System för hydrologisk och meteorologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål" (SKB MD 368.010), cf. Table 1-1.

4.2 Preparations

The preparations included mixing of the tracer stock solution, function checks of the equipment and printing of field protocols and labels with sample numbers.

4.3 Execution of field work

The borehole sections included in the monitoring program during the test campaign 2015–2016 are listed in Table 4-1.

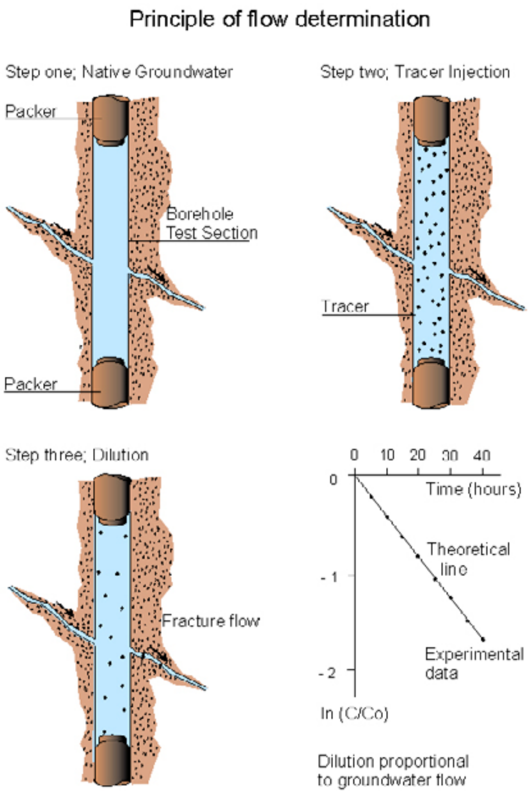

Figure 4-1. General principles of dilution and flow determination.

Table 4-1. Borehole sections included in the monitoring program, test campaign 2015–2016.

Borehole:section	Depth (m)	T (m^2/s)	Geologic character***	Test period (yymmdd)
KFM08D:2	825–835	2 E-8*	Single fracture	150909–151012 151028–160614
KFM08D:4	660–680	2 E-7*	Single fracture	150917–151012 151028–160705
KFM10A:2	430–440	3 E-5*	Zone ZFMA2	150903–160705
KFM11A:4	446–456	6 E-7*	Not included in Follin et al. (2008)	150904–160705
HFM13:1	159–173	3 E-4**	Zone ZFMENE0401A	150904–160620
HFM21:3	22–32	4 E-5**	Single fracture, Fracture domain FFM02	150903–160619

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements (Kristiansson 2007, Sokolnicki et al. 2006, Harrström et al. 2007, Väisäsvaara and Pekkanen 2007).

** From HTHB (HydroTester HammarBorrhål) measurements (Ludvigson et al. 2004, Jönsson et al. 2005).

*** Deformation zones according to Forsmark modelling, stage 2.2 (Follin et al. 2007).

The tests were made by injecting a finite volume of tracer solution (Amino-G acid, 1 000 mg/l) into the selected borehole sections and allowing the natural groundwater flow to dilute the tracer. The tracer was injected during a time period equivalent to the time needed to circulate one section volume. The injection/circulation flow ratio was set to 1/1 000, implying that the initial concentration in the borehole section should be about 1 mg/l for Amino-G acid. All six sections were measured simultaneously. The tracer solution was continuously circulated and sampled using the equipment described in Section 3.2.

This year no interruptions in the measurements due to groundwater sampling were made in any of the measured sections.

In borehole sections HFM13:1 and KFM10A:2, the dilution of tracer was quite fast and tracer injections had to be frequently repeated. In HFM13 tracer injections were made about once a month and sampling was temporarily ended about two weeks after each injection when the tracer concentration had been diluted to background level.

The samples were analysed for dye tracer content at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer.

4.4 Analyses and interpretations

Flow rates were calculated from the decay of tracer concentration versus time through dilution with natural, unlabelled groundwater, cf. Gustafsson (2002). The so-called “dilution curves” were plotted as the natural logarithm of concentration versus time. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time, t (s):

$$\ln (c/c_0) = -(Q_{bh}/V) \cdot t \qquad (4\text{-}1)$$

where Q_{bh} (m^3/s) is the groundwater flow rate through the borehole section and V (m^3) is the volume of the borehole section. By plotting ln (c/c_0) or ln c versus t, and by knowing the borehole volume V, Q_{bh} may then be obtained from the straight-line slope.

The sampling procedure with a constant flow rate of approximately 0.06 ml/min also creates a dilution of tracer. The sampling flow rate is therefore subtracted from the value obtained from Equation 4-1.

The flow, Q_{bh}, may be translated into a Darcy velocity by taking into account the distortion of the flow caused by the borehole and the angle between the borehole and flow direction. In practice, a 90° angle between the borehole axis and the flow direction is assumed and the relation between the flow in the rock, the Darcy velocity, v (m/s), and the measured flow through the borehole section, Q_{bh}, can be expressed as:

$$Q_{bh} = v \cdot L_{bh} \cdot 2r_{bh} \cdot \alpha \qquad (4\text{-}2)$$

where L_{bh} is the length of the borehole section (m), r_{bh} is the borehole radius (m) and α is the factor accounting for the distortion of flow caused by the borehole.

Hydraulic gradients are roughly estimated from Darcy's law where the gradient, I, is calculated as the function of the Darcy velocity, v, with the hydraulic conductivity, K (m/s):

$$I = \frac{v}{K} = \frac{Q_{bh} \cdot L_{bh}}{\alpha \cdot A \cdot T_{bh}} = \frac{Q_{bh} \cdot L_{bh}}{2 \cdot d_{bh} \cdot L_{bh} \cdot T_{bh}} \qquad (4\text{-}3)$$

where T_{bh} (m^2/s) is the transmissivity of the section, obtained from PSS or HTHB measurements, A the cross section area between the packers, and d_{bh} (m) the borehole diameter.

The factor α is commonly given the value 2 in the calculations, which is the theoretical value for a homogeneous porous medium. Since the rock is mostly heterogeneous, and because the angles between the borehole axis and the flow direction in the sections are not always 90°, the calculation of the hydraulic gradient is a rough estimation.

4.5 Nonconformities

The modified borehole instrumentation in KFM08D requires the circulation pumps to be connected through gas-sealed docking devices instead of using mini-packers. Unfortunately, the docking mechanism was released in both sections in the middle of October 2015 due to a gas leakage. The measurements were re-started in the end of October.

Due to a malfunctioning sampler in KFM11A samples are missing for about two weeks in the later part of October 2015.

The measurement in HFM21 was accidently terminated about two weeks in advance, probably due to a power failure that occurred in the middle of June 2016. The peristaltic pump for sampling does not start automatically when the power is back and unfortunately this was not noticed during the weekly checks.

Each sampler was placed in a plastic box together with four small bottles containing fresh water in order to prevent, or at least reduce, evaporation. However, evaporation of water from the samples, resulting in false higher values of tracer concentration could still be seen, especially during the winter period when the air is drier and the electric heaters in the containers are on. No correction of data has been made because it has not been possible to determine to which extent each sample has been affected.

5 Results

5.1 General

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP SFK-15-014). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. However, such revision of the database will not necessarily result in a revision of this report, although the normal procedure is that major data revisions entail a revision also of the report.

5.2 Test campaign 11, 2015–2016

An example of a typical tracer dilution curve is shown in Figure 5-1. The flow rate is calculated from the slope of the straight-line fit. Tracer dilution graphs for each borehole section are presented in Appendix 1.

A summary of the results obtained is presented in Table 5-1 including measured groundwater flow rates, Darcy velocities and hydraulic gradients together with transmissivities and volumes of the borehole sections. Measured flow rates during the measurement period September 2015–July 2016 are shown graphically in Figure 5-2 for each section.

In Appendix 2 the groundwater level during the entire test period is presented for the selected boreholes, see also Table 4-1 for actual measurement periods for each section. Some activities that were performed in the Forsmark area during the test period, and thus may have affected the ongoing groundwater flow measurements, are compiled in Table 5-2.

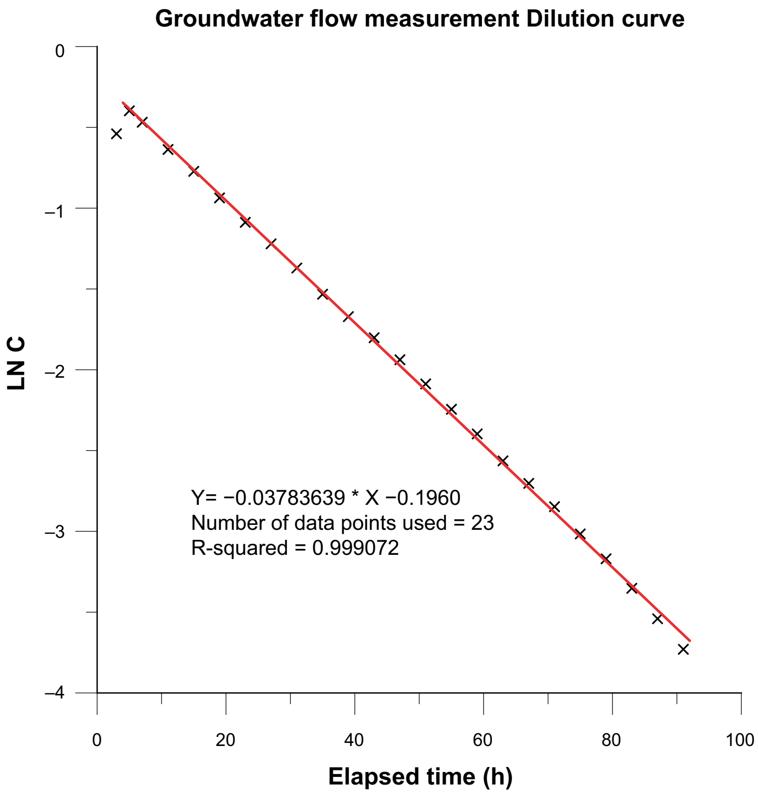

Figure 5-1. *Example of a tracer dilution graph (logarithm of concentration versus time), including straight-line fit.*

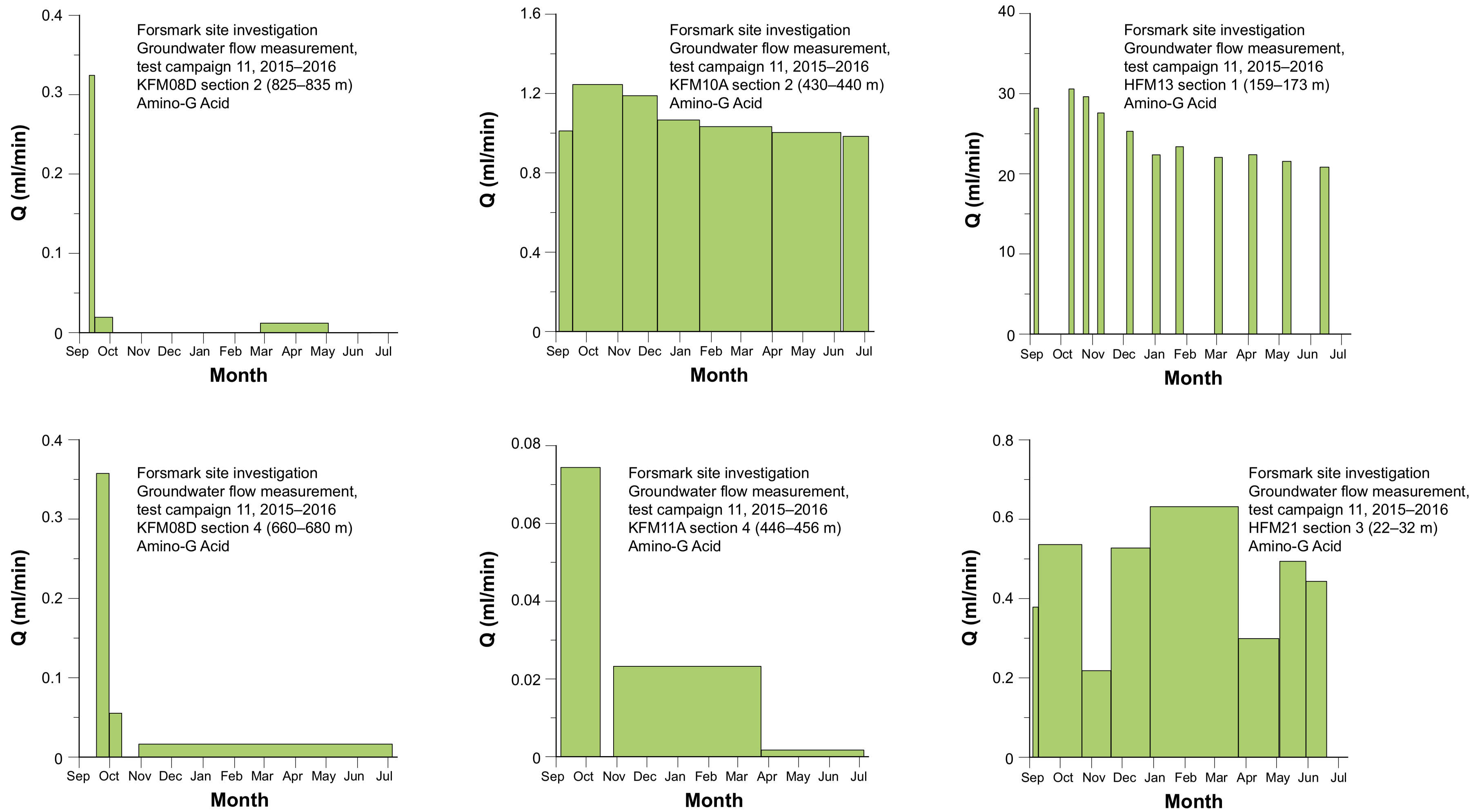

Figure 5-2. *Measured flow rates Sep 2015 – Jul 2016 for each section, test campaign 11, 2015-2016.*

The results show that the groundwater flow varies a lot over the year in most of the measured sections. In the deepest sections with the lowest transmissivities (KFM08D:2 and :4 and also KFM11A:4) the flow measured during the first 200 up to 1 000 hours is twenty to thirty times higher compared to the flow towards the end of the measurement period. This is probably due to effects at start-up such as the mixing procedure and/or the injection process causing disturbances resulting in an enhanced flow. However, this effect was not seen in any of the sections in KFM08D when the start-up procedure was repeated after the equipment problems that occurred (see below).

Another problem with the measurements in these three sections is that the flow in the later part of the measured period is very low compared to the sampling flow rate. In KFM08D:2 it is difficult or even impossible to get any flow rate at all for the later part after the sampling rate has been subtracted. One could also expect that the sampling rate, calculated from the measured sample volume in the tubes, is somewhat underestimated due to evaporation. Concentration data are also very scattered, especially during the winter period, due to the evaporation problems discussed further down. In Appendix 1 two dilution graphs for KFM08D:2 are presented, one graph containing all data and one where data from about 2 000 to 4 000 hours have been omitted. However, no reliable flow rates could be evaluated after 2 000 hours of measurement whether data were excluded or not.

In general, the equipment has worked well and no major hydraulic disturbance has occurred during the tests, cf. Appendix 2. The measurements in both sections in borehole KFM08D were interrupted after about 600–700 hours for about two weeks (400 hours) when the docking equipment accidently was released due to gas leakage. Also in KFM11A there was a break in the measurement for about two weeks, in this case after 1 000 hours due to a malfunctioning sampler. There were also minor interruptions in some sections due to power failures and clogging of tubes. However, none of this is considered to have affected the results.

During the long-term measurements performed 2013 (test campaign no. 9) a problem with evaporation of water from the samples was discovered (Wass 2015). This time, as last year, each sampler was placed in a plastic box together with four small bottles containing fresh water in order to prevent, or at least reduce, evaporation. Attendance was made about once a week including collection of samples, in-between the sampling tubes were open without caps inside the plastic box. When water evaporates from a sample the concentration of tracer becomes higher. Some effect of this could still be seen in most measured sections, with sudden jumps in tracer concentration that coincide with a set of collected samples. The influence of evaporation is also more obvious during the winter period when the air is drier and the electric heaters in the containers are on, see the dilution curves for KFM08D and KFM11A:4 in Appendix 1. No correction of data has been made because it has not been possible to determine to which extent each sample has been affected.

The results show that the groundwater flow during natural conditions varies from 0.002 to 31 ml/min in the measured sections with Darcy velocities ranging from 1.8×10^{-11} to 1.3×10^{-7} m/s.

Hydraulic gradients are calculated according to the Darcy concept and are within the expected range in the majority of the measured sections. It should be noted that the Darcy concept is built on assumptions of a homogeneous porous medium and values for a fractured medium should therefore be treated with great care. In KFM08D:2 and also for the first 300 hours in KFM08D:4 the hydraulic gradient is very large. This indicates that the flow rates measured during these periods are higher than expected. The large gradients may also be due to rough estimates of the correction factor, α, and/or the hydraulic conductivity of the fracture.

Table 5-1. Results from groundwater flow measurements, test campaign 11, 2015–2016.

Borehole/ section	Depth (m)	Transmissivity (m^2/s)	Vol. (l)	Time interval (h) From	To	Measured flow, Q (ml/min)	Darcy velocity, v (m/s)	Hydraulic gradient, I (m/m)
KFM08D:2	**825–835**	**2E-08***	**62.64**	**30**	**150**	**0.3**	**3.6E-09**	**1.8**
				155	580	0.02	2.2E-10	0.1
				1190	4060	–	–	–
				4070	5675	0.01	1.4E-10	0.1
				5685	6685	–	–	–
KFM08D:4	**660–680**	**2E-07***	**63.33**	**15**	**310**	**0.4**	**2.0E-09**	**0.2**
				320	615	0.06	3.1E-10	0.03
				1000	7005	0.02	9.5E-11	0.01
KFM10A:2	**430–440**	**3E-05***	**39.52**	**15**	**325**	**1.0**	**1.1E-08**	**0.004**
				330	1510	1.2	1.4E-08	0.005
				1520	2320	1.2	1.3E-08	0.004
				2345	3330	1.1	1.2E-08	0.004
				3340	5030	1.0	1.1E-08	0.004
				5050	6670	1.0	1.1E-08	0.004
				6725	7325	1.0	1.1E-08	0.004
KFM11A:4	**446–456**	**6E-07***	**40.47**	**30**	**1000**	**0.07**	**8.0E-10**	**0.01**
				1300	4840	0.02	2.5E-10	0.004
				4850	7320	0.002	1.8E-11	0.0003
HFM13:1	**159–173**	**3E-04****	**39.28**	**15**	**115**	**28**	**1.2E-07**	**0.006**
				830	950	31	1.3E-07	0.006
				1170	1295	30	1.3E-07	0.006
				1500	1655	28	1.2E-07	0.006
				2185	2335	25	1.1E-07	0.005
				2780	2965	22	9.8E-08	0.005
				3330	3510	23	1.0E-07	0.005
				4240	4425	22	9.7E-08	0.005
				5045	5235	22	9.8E-08	0.005
				5835	6035	22	9.5E-08	0.005
				6715	6920	21	9.2E-08	0.004
HFM21:3	**22–32**	**4E-05****	**31.39**	**20**	**145**	**0.4**	**2.3E-09**	**0.0006**
				150	1170	0.5	3.2E-09	0.0008
				1175	1860	0.2	1.3E-09	0.0003
				1865	2785	0.5	3.2E-09	0.0008
				2790	4865	0.6	3.8E-09	0.0009
				4875	5805	0.3	1.8E-09	0.0004
				5850	6465	0.5	3.0E-09	0.0007
				6475	6960	0.4	2.7E-09	0.0007

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements (Kristiansson 2007, Sokolnicki et al. 2006, Harrström et al. 2007, Väisäsvaara and Pekkanen 2007).

** From HTHB (HydroTester HammarBorrhål) measurements (Ludvigson et al. 2004, Jönsson et al. 2005).

Table 5-2. Activities performed in the Forsmark area during the test campaign with groundwater flow measurements, 2015-2016.

Start date	Stop date	Borehole	Activity
Test campaign no. 11, 2015-09-03 to 2016-07-06			
2015-09-13	2015-09-21	KFM08A:6	Groundwater sampling
2015-09-14	2015-09-14	KFM08A:2	Groundwater sampling
2015-12-09	2015-12-14	KFR27	Interference test pumping hole
2016-02-23	2016-02-26	KFR27	Interference test pumping hole
2016-03-30	2016-04-04	KFM24	Percussion drilling
2016-04-01	2016-04-04	KFR103	Interference test pumping hole
2016-04-07	2016-04-11	KFR103	Interference test pumping hole
2016-04-10	2016-06-13	KFM24	Core drilling
2016-04-26	2016-04-29	KFR105	Interference test pumping hole
2016-06-08	2016-06-10	KFM11A:2	Groundwater sampling

5.3 Flow rate comparison

For comparison reasons flow rates obtained from previously performed test campaigns are compiled in Table 5-3.

The comparison shows that the flow rates measured 2015–2016 are within the range of the values measured in previous campaigns in most borehole sections. Previous measurements in both sections in KFM08D gave unreasonably high flow rates. This was due to leakage in the borehole equipment. The borehole was re-instrumented during 2014 and this year's measurements are the first made since then. In KFM10A:2 similar flow rates were measured throughout the entire period and they are also consistent with the results from earlier years. In KFM11A:4 a considerably lower flow rate than ever before was measured in the last part of the test period. As discussed in Section 5.2, the flow rate measured during the first 1 000 hours in KFM11A:4 is more than thirty times higher compared to the flow towards the end of the measurement period. In previous test campaigns the measurement duration has been about 200 hours, why the flow rates presented in Table 5-3 probably are overestimated. The evaluated flow rates during the first 1 700 hours in HFM13:1 were somewhat higher than ever measured before in the borehole section and compared to the results from 2011 and 2012 the flow rates measured during 2015–2016 were five to ten times higher. In HFM21:3 the flow rates were more varying through the measured period and were about two to ten times lower than during previous test campaigns.

Table 5-3. Results from groundwater flow measurements in previously performed test campaigns in the selected borehole sections.

Borehole: sec	2005 (Wass 2006) (ml/min)	2006 (Wass 2007) (ml/min)	2007 (Wass 2008) (ml/min)	2008 (Wass 2009) (ml/min)	2009 (Wass 2010) (ml/min)	2010 (Thur and Wass 2011) (ml/min)	2011 (Thur and Wass 2012) (ml/min)	2012 (Ragvald and Wass 2013) (ml/min)	2015–2016 (ml/min)
KFM08D:2	–	–	2.6	1.8	4.1	0.9	2.1	–	0–0.3
KFM08D:4	–	–	91	123	21	55	53	–	0.02–0.4
KFM10A:2	–	–	2.7	1.6	1.2	1.4	1.4	1.4	1.0–1.2
KFM11A:4	–	–	0.04	0.01	0.03	0.2	0.04	0.3	0.002–0.07
HFM13:1	24	4.3	13	17	8.2	12	3.9	3.3	21–31
HFM21:3	–	–	1.9	2.1	1.0	1.0	0.9	1.1	0.2–0.6

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements (Kristiansson 2007, Sokolnicki et al. 2006, Harrström et al. 2007, Väisäsvaara and Pekkanen 2007).

** From HTHB (HydroTester HammarBorrhål) measurements (Ludvigson et al. 2004, Jönsson et al. 2005).

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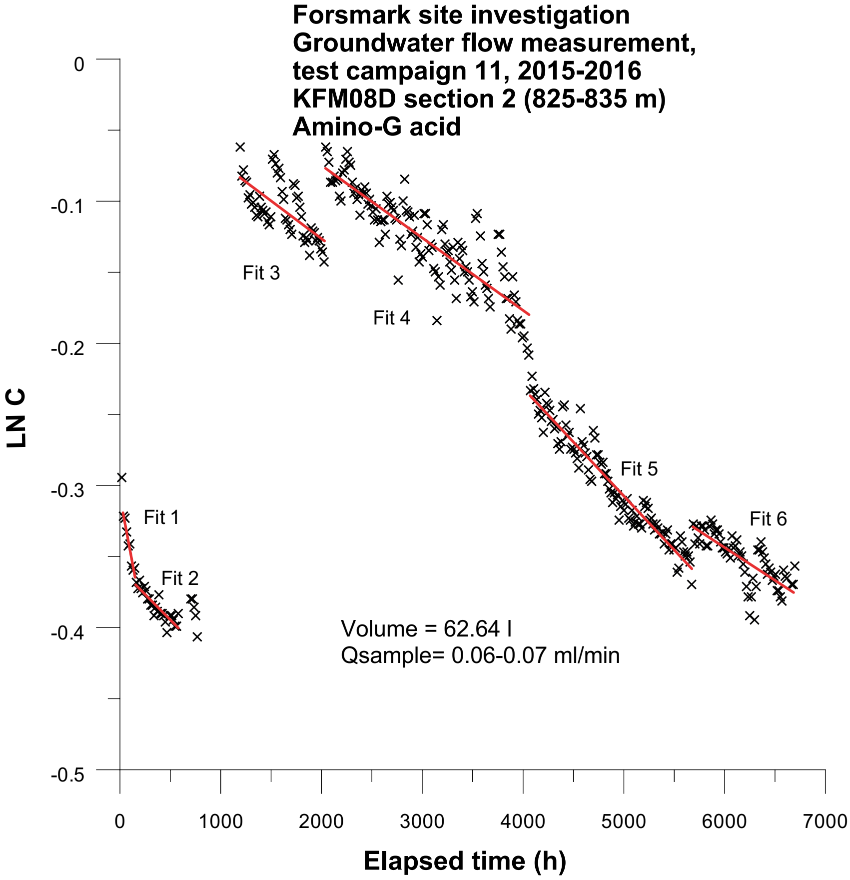
Appendix 1

Tracer dilution graphs



Fit 1: 30-150 h
Y = -0.00037878 * X - 0.3078
Number of data points used = 8
R-squared = 0.935359
Q= 0.3 ml/min

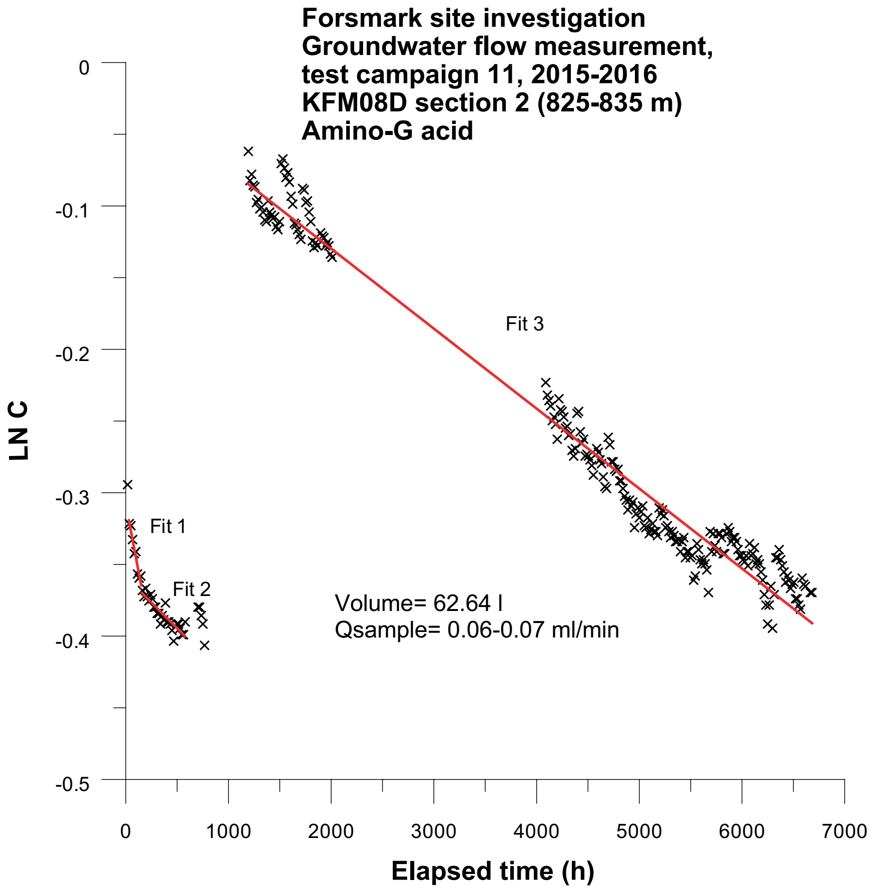
Fit 2: 155-580 h
Y = -7.1749E-005 * X - 0.3587
Number of data points used = 26
R-squared = 0.784702
Q= 0.02 ml/min

Fit 3: 1190-2030 h
Y = -5.3175E-005 * X - 0.0200
Number of data points used = 53
R-squared = 0.449726
Q= -0.01 ml/min

Fit 4: 2040-4060 h
Y = -5.0987E-005 * X + 0.0272
Number of data points used = 121
R-squared = 0.774423
Q= -0.01 ml/min

Fit 5: 4070-5675 h
Y = -7.5887E-005 * X + 0.0721
Number of data points used = 101
R-squared = 0.936523
Q= 0.01 ml/min

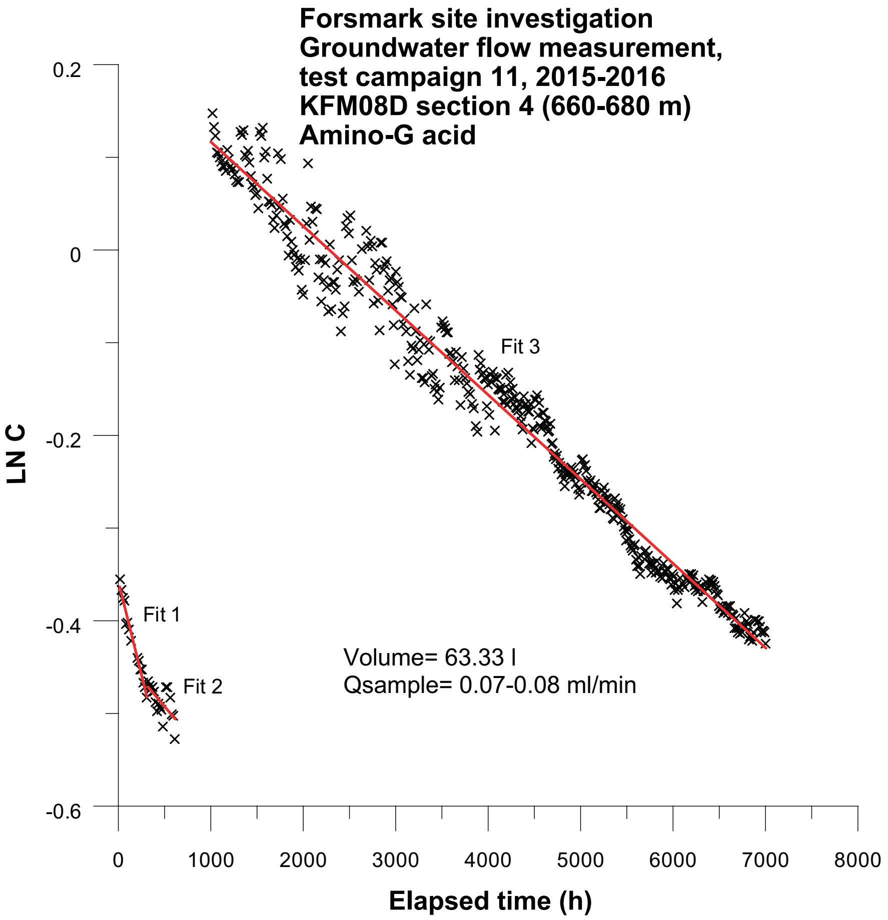
Fit 6: 5685-6685 h
Y = -4.6225E-005 * X - 0.0663
Number of data points used = 61
R-squared = 0.580146
Q= -0.02 ml/min



Fit 1: 30-150 h
Y = -0.00037878 * X - 0.3078
Number of data points used = 8
R-squared = 0.935359
Q= 0.3 ml/min

Fit 2: 155-580 h
Y = -7.1749E-005 * X - 0.3587
Number of data points used = 26
R-squared = 0.784702
Q= 0.02 ml/min

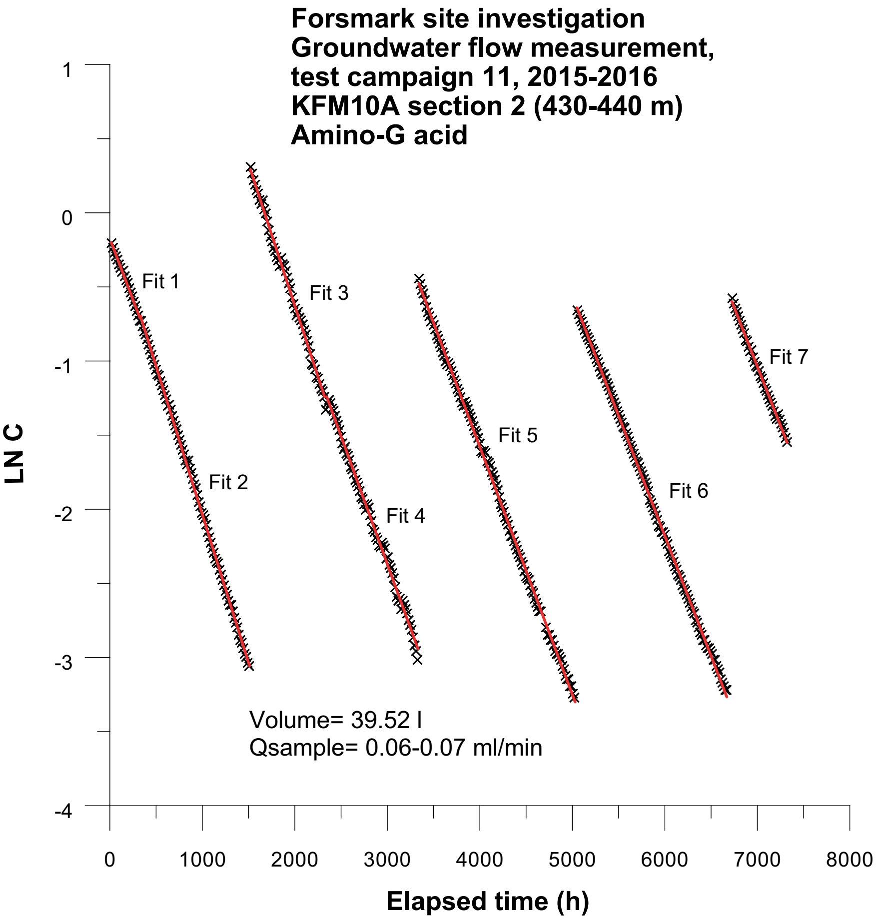
Fit 3: 1190-6685 h
Y = -5.5781E-005 * X - 0.0182
Number of data points used = 211
R-squared = 0.97621
Q= -0.01 ml/min



Fit 1: 15-310 h
Y = -0.00040387 * X - 0.3573
Number of data points used = 15
R-squared = 0.977552
Q= 0.4 ml/min

Fit 2: 320-615 h
Y = -0.00011784 * X - 0.4336
Number of data points used = 17
R-squared = 0.395802
Q= 0.06 ml/min

Fit 3: 1000-7005 h
Y = -9.0958E-005 * X + 0.2076
Number of data points used = 428
R-squared = 0.974838
Q= 0.02 ml/min



Fit 1: 15-325 h
Y = -0.00164748 * X - 0.1752
Number of data points used = 20
R-squared = 0.993053
Q= 1.0 ml/min

Fit 2: 330-1510 h
Y = -0.00200089 * X - 0.03572
Number of data points used = 74
R-squared = 0.999201
Q= 1.2 ml/min

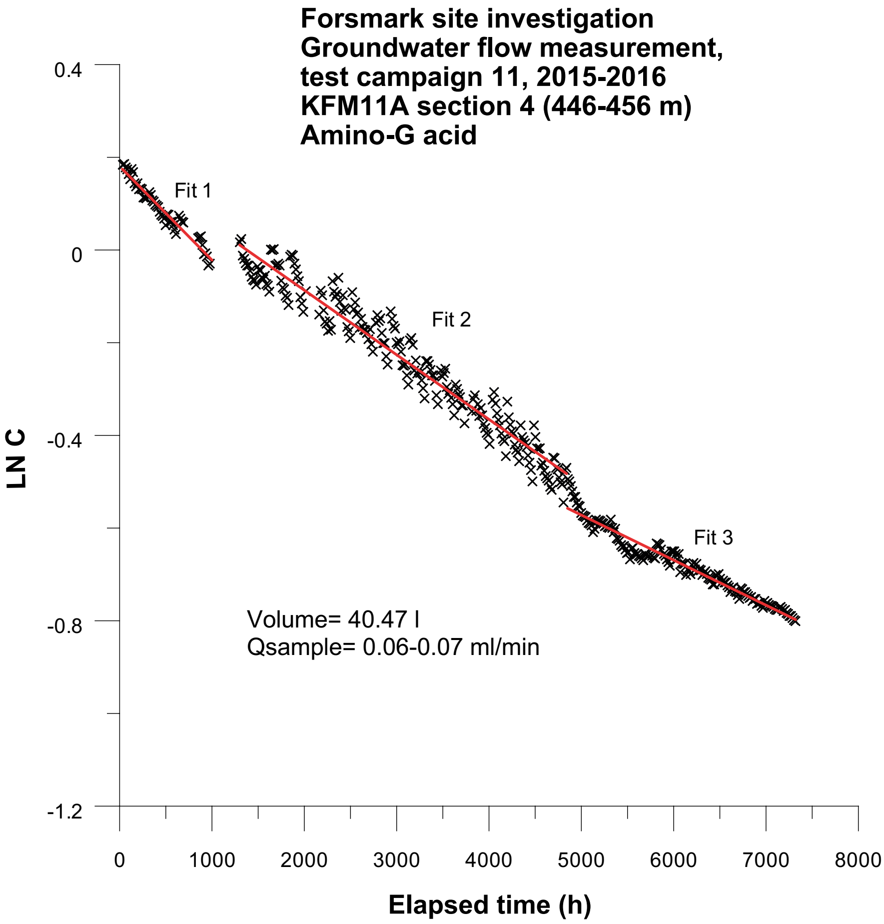
Fit 3: 1520-2320 h
Y = -0.00191294 * X + 3.20
Number of data points used = 49
R-squared = 0.995951
Q= 1.2 ml/min

Fit 4: 2345-3330 h
Y = -0.00172483 * X + 2.80
Number of data points used = 62
R-squared = 0.996002
Q= 1.1 ml/min

Fit 5: 3340-5030 h
Y = -0.00167059 * X + 5.103
Number of data points used = 103
R-squared = 0.998852
Q= 1.0 ml/min

Fit 6: 5050-6670 h
Y = -0.00162093 * X + 7.545
Number of data points used = 102
R-squared = 0.999375
Q= 1.0 ml/min

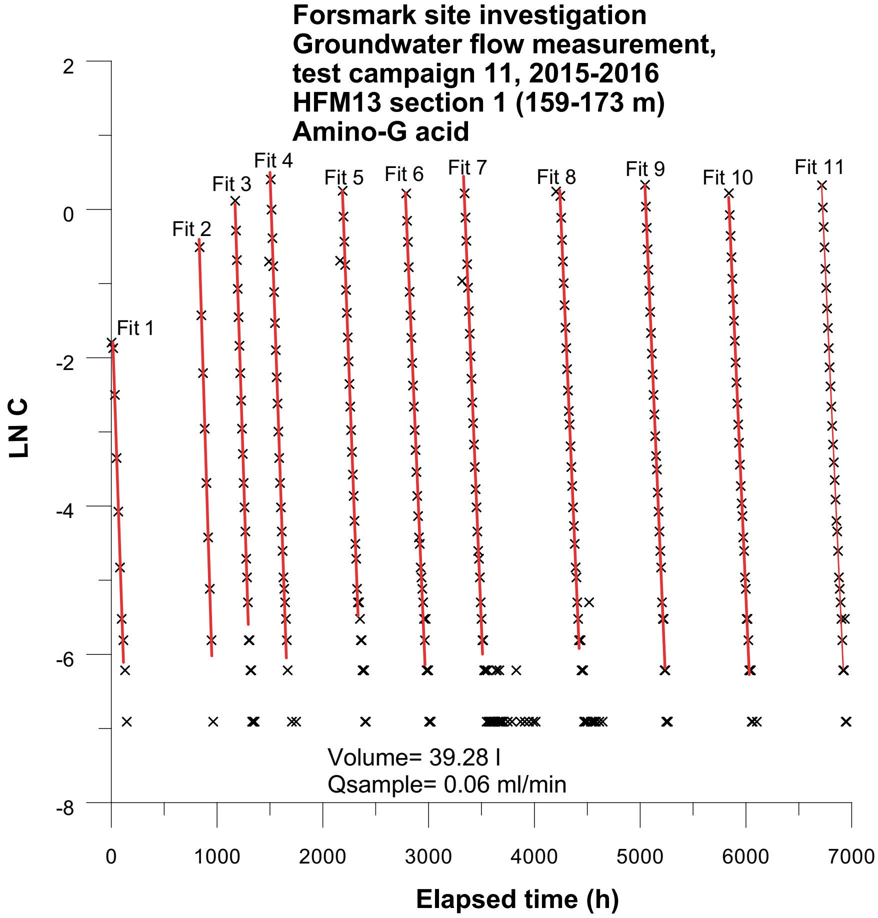
Fit 7: 6725-7325 h
Y = -0.00159357 * X + 10.12
Number of data points used = 38
R-squared = 0.996599
Q= 1.0 ml/min



Fit 1: 30-1000 h
Y = -0.00020234 * X + 0.1806
Number of data points used = 50
R-squared = 0.949453
Q= 0.07 ml/min

Fit 2: 1300-4840 h
Y = -0.00013936 * X + 0.1919
Number of data points used = 205
R-squared = 0.948692
Q= 0.02 ml/min

Fit 3: 4850-7320 h
Y = -0.00009726 * X - 0.0856
Number of data points used = 153
R-squared = 0.94979
Q= 0.002 ml/min



Fit 1: 15-115 h
Y = -0.04315129 * X - 1.146
Number of data points used = 7
R-squared = 0.990211
Q= 28 ml/min

Fit 2: 830-950 h
Y = -0.04681798 * X + 38.46
Number of data points used = 8
R-squared = 0.998392
Q= 31 ml/min

Fit 3: 1170-1295 h
Y = -0.04533742 * X + 53.12
Number of data points used = 16
R-squared = 0.998587
Q= 30 ml/min

Fit 4: 1500-1655 h
Y = -0.04224255 * X + 63.86
Number of data points used = 19
R-squared = 0.993189
Q= 28 ml/min

Fit 5: 2185-2335 h
Y = -0.03874436 * X + 84.91
Number of data points used = 19
R-squared = 0.999255
Q= 25 ml/min

Fit 6: 2780-2965 h
Y = -0.03425356 * X + 95.45
Number of data points used = 23
R-squared = 0.990473
Q= 22 ml/min

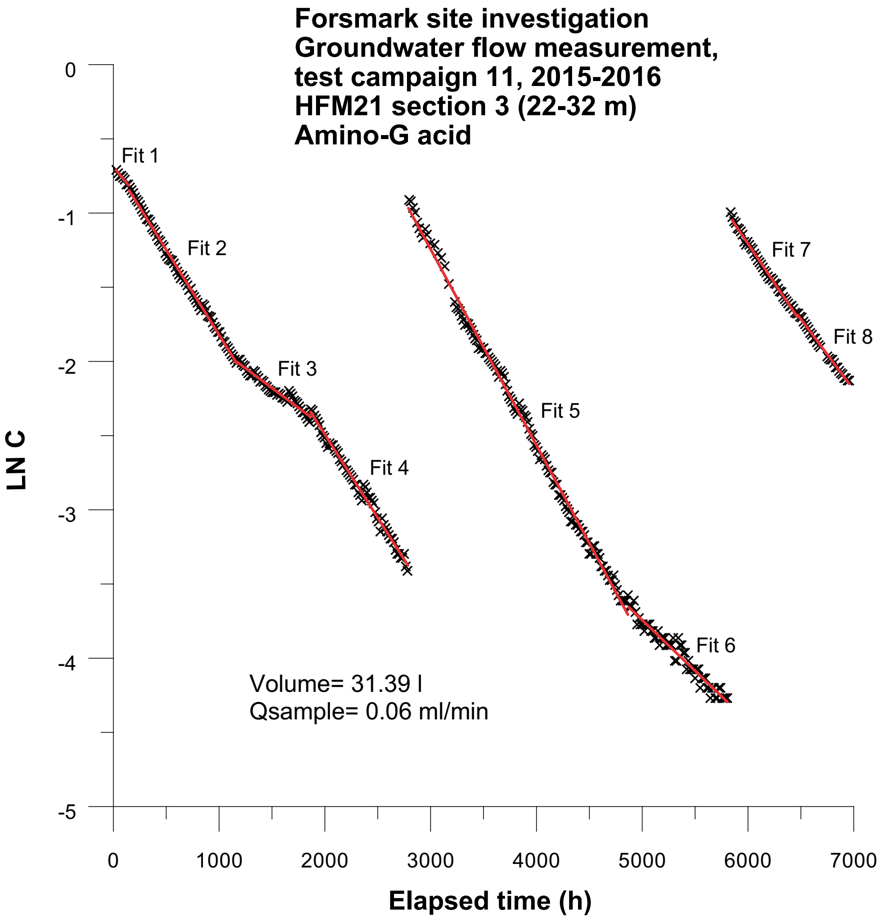
Fit 7: 3330-3510 h
Y = -0.03580682 * X + 119.7
Number of data points used = 22
R-squared = 0.997344
Q= 23 ml/min

Fit 8: 4240-4425 h
Y = -0.03377555 * X + 143.5
Number of data points used = 23
R-squared = 0.998993
Q= 22 ml/min

Fit 9: 5045-5235 h
Y = -0.03428154 * X + 173.3
Number of data points used = 24
R-squared = 0.998481
Q= 22 ml/min

Fit 10: 5835-6035 h
Y = -0.03301592 * X + 192.9
Number of data points used = 25
R-squared = 0.998061
Q= 22 ml/min

Fit 11: 6715-6920 h
Y = -0.03190446 * X + 214.6
Number of data points used = 26
R-squared = 0.998903
Q= 21 ml/min



Fit 1: 20-145 h
Y = -0.00085444 * X - 0.6893
Number of data points used = 8
R-squared = 0.949229
Q= 0.4 ml/min

Fit 2: 150-1170 h
Y = -0.00114572 * X - 0.6752
Number of data points used = 64
R-squared = 0.997278
Q= 0.5 ml/min

Fit 3: 1175-1860 h
Y = -0.00053336 * X - 1.379
Number of data points used = 43
R-squared = 0.952922
Q= 0.2 ml/min

Fit 4: 1865-2785 h
Y = -0.00112420 * X - 0.2435
Number of data points used = 58
R-squared = 0.989861
Q= 0.5 ml/min

Fit 5: 2790-4865 h
Y = -0.00132004 * X + 2.716
Number of data points used = 118
R-squared = 0.996948
Q= 0.6 ml/min

Fit 6: 4875-5805 h
Y = -0.00068502 * X - 0.3177
Number of data points used = 58
R-squared = 0.950781
Q= 0.3 ml/min

Fit 7: 5850-6465 h
Y = -0.00105800 * X + 5.141
Number of data points used = 39
R-squared = 0.995805
Q= 0.5 ml/min

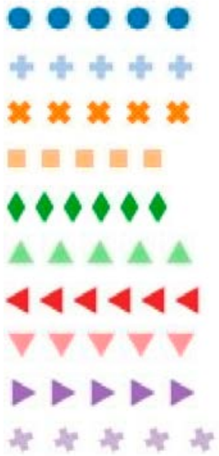
Fit 8: 6475-6960 h
Y = -0.00095446 * X + 4.489
Number of data points used = 28
R-squared = 0.995008
Q= 0.4 ml/min

Groundwater levels (m.a.s.l. RHB70)

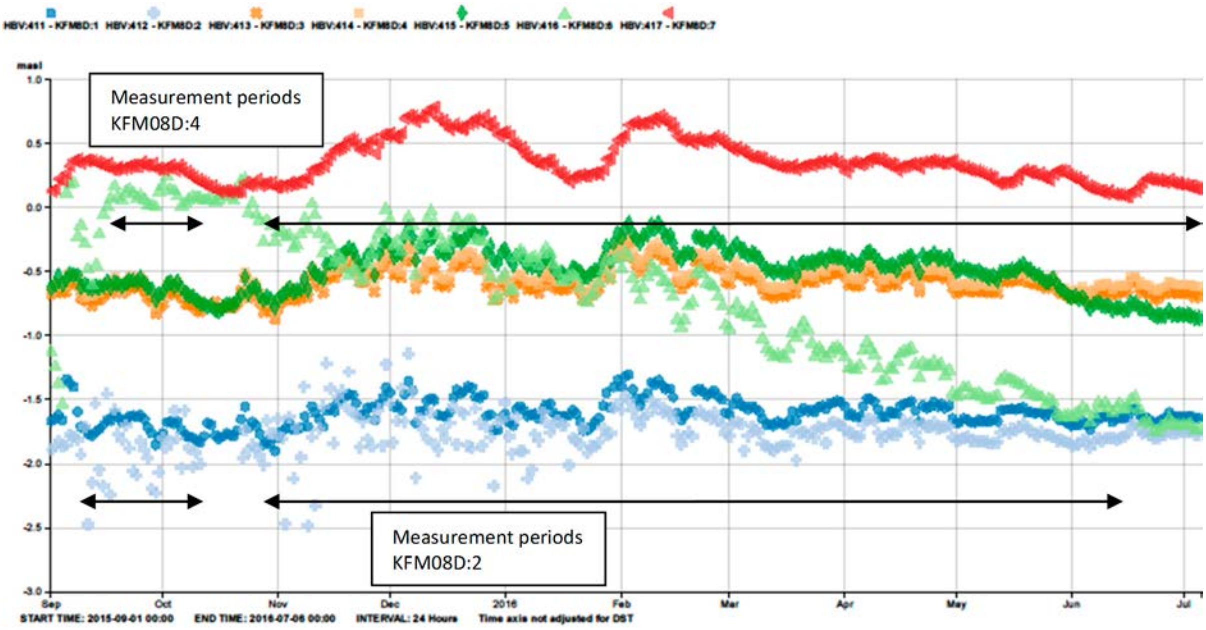
2015-09-01 to 2016-07-06

The symbols and colours representing the various borehole sections in the diagrams are:

The deepest section = section 1
section 2
section 3
section 4
section 5
section 6
section 7
section 8
section 9
section 10

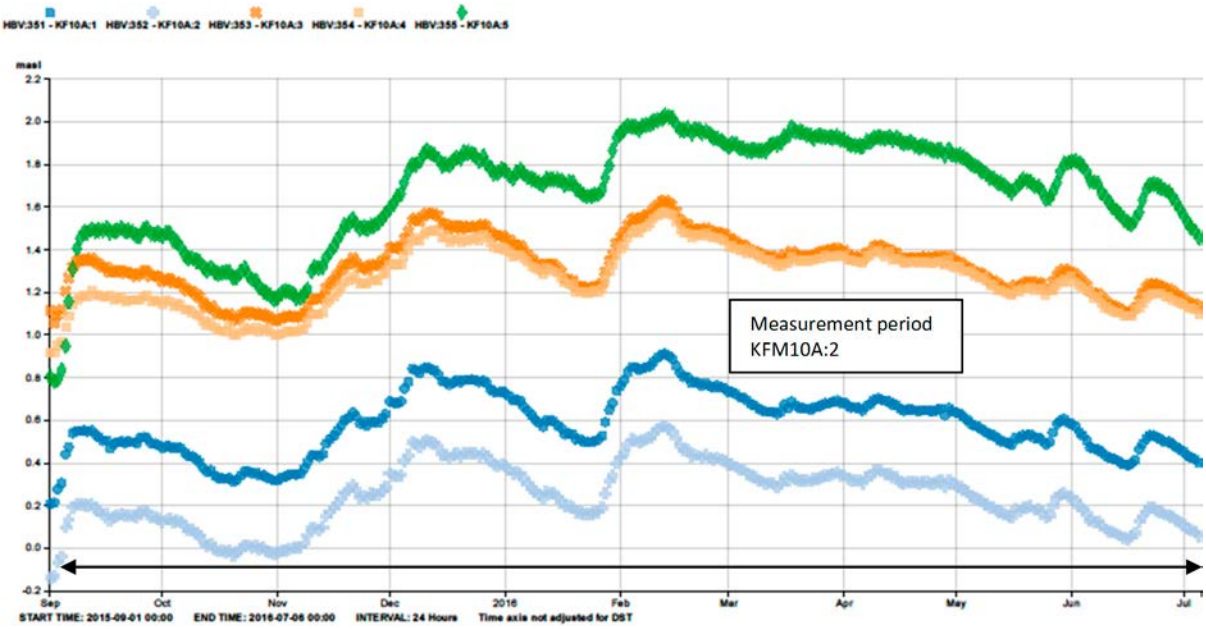


KFM08D



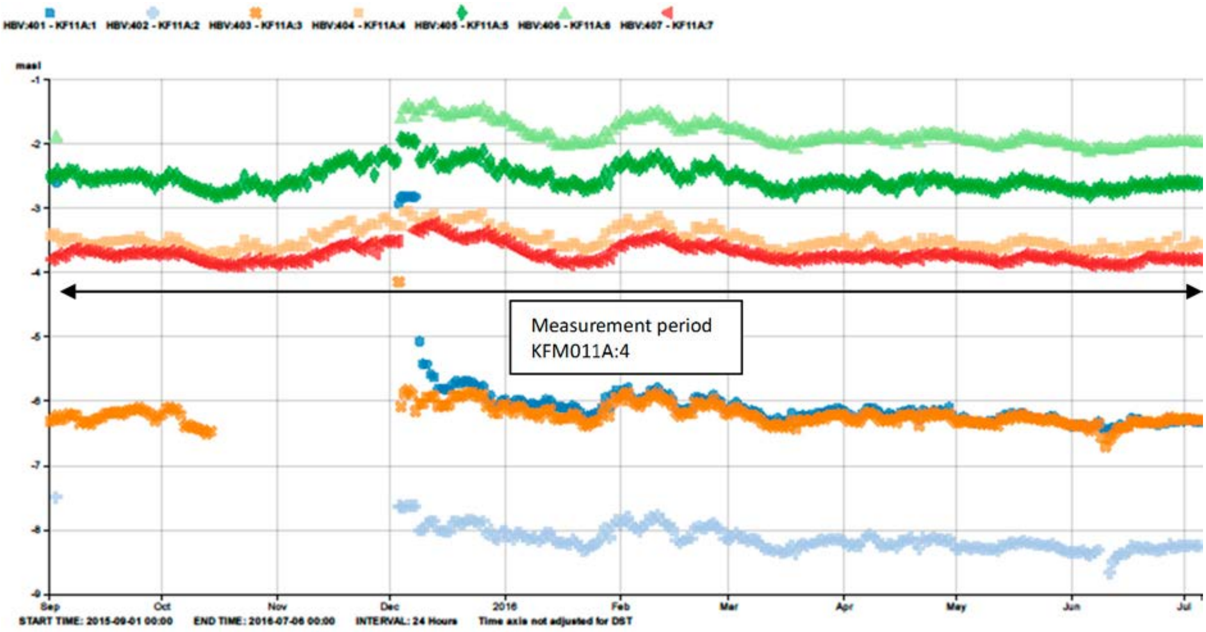
Measured sections: KFM08D:2 (pale blue) and KFM08D:4 (pale orange).

KFM10A



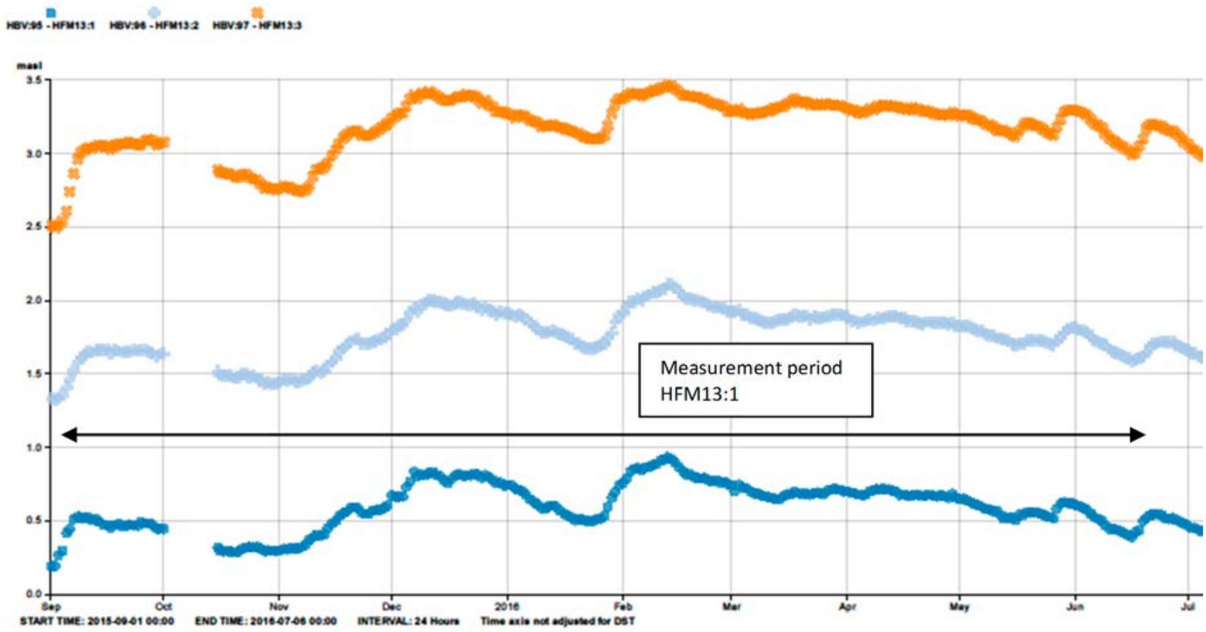
Measured section: KFM10A:2 (pale blue).

KFM11A



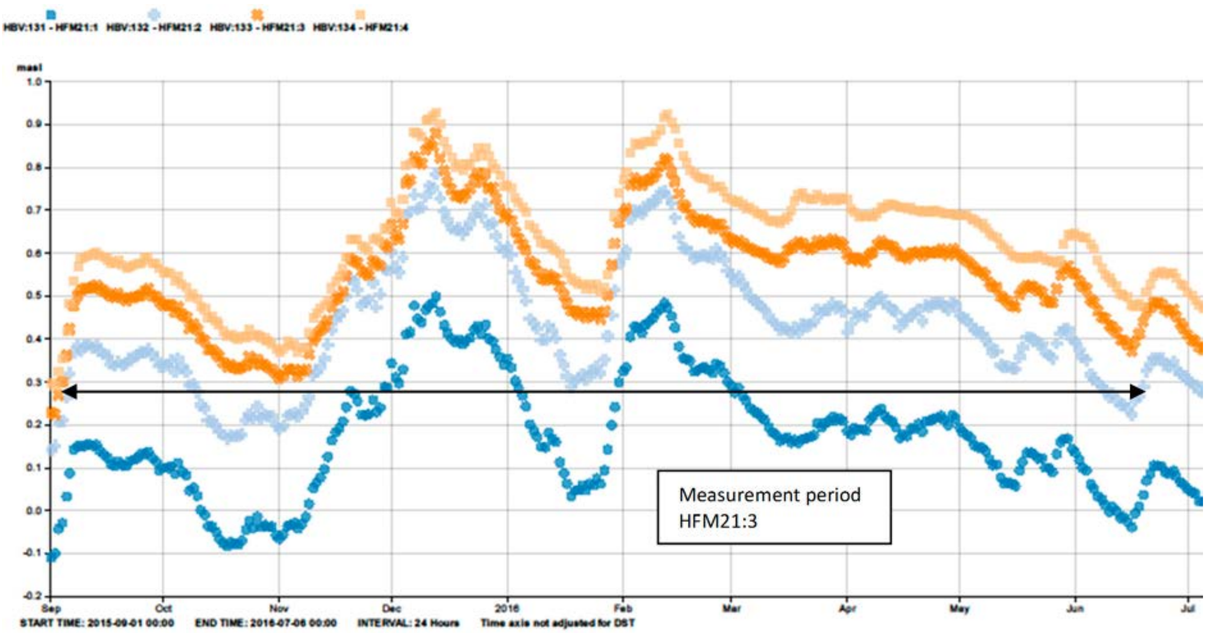
Measured section: KFM11A:4 (pale orange).

HFM13



Measured section: HFM13:1 (dark blue).

HFM21



Measured section: HFM21:3 (orange)

Briefly describe the activity that has been performed and results that have been obtained (include significant nonconformities from activity plan and method description).

Arkitektkopia AB, Bromma, 2018

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